

EFFECT OF TUBE-BASED X-RAY MICROTOMOGRAPHY IMAGING ON THE AMINO ACID AND AMINE CONTENT OF THE MURCHISON CM2 CHONDRITE. D. P. Glavin¹, J. M. Friedrich^{2,3}, J. C. Apon-
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Introduction: X-ray and synchrotron X-ray micro-
computed tomography (μ CT) are increasingly being
used for three dimensional reconnaissance imaging of
chondrites and returned extraterrestrial material prior
to detailed chemical and mineralogical analyses [1,2].
Although μ CT imaging is generally considered to be a
non-destructive technique since silicate and metallic
minerals in chondrites are not affected by X-ray expo-
sures at the intensities and wavelengths typically used,
there are concerns that the use of μ CT could be detri-
mental to the organics in carbonaceous chondrites. We
recently conducted a synchrotron μ CT experiment on a
powdered sample of the Murchison CM2 carbonaceous
chondrite exposed to a monochromatic high energy
(~48 keV) total X-ray radiation dose of ~1 kilogray
(kGy) using the Advanced Photon Source beamline 13-
BMD at Argonne National Laboratory and found that
there were no detectable changes in the amino acid
abundances or enantiomeric compositions in the chon-
drite after exposure relative to a Murchison control
sample that was not exposed [3].

However, lower energy bremsstrahlung X-rays
could interact more with amino acids and other lower
molecular weight amines in meteorites. To test for this
possibility, three separate μ CT imaging experiments of
the Murchison meteorite using the GE Phoenix
v|tome|x s 240 kV microfocus high resolution tungsten
target X-ray tube instrument at the American Museum
of Natural History (AMNH) were conducted and the
amino acid abundances and enantiomeric compositions
were determined. We also investigated the abundances
of the C1-C5 amines in Murchison which were not
analyzed in the first study [3].

Materials and Methods: A single 10 g fragment
of the Murchison meteorite (“Grade A”, Chicago Field
Museum) was crushed to a powder and homogenized
by mixing using a ceramic mortar and pestle inside a
positive pressure HEPA filtered laminar flow hood at
NASA’s Goddard Space Flight Center (GSFC). All
glassware, ceramics and sample handling tools were
pyrolyzed at 500 °C in air overnight. Four separate
aliquots (~0.5 g each) of the meteorite powder were
transferred to individual borosilicate glass screw
capped vials and sealed in air for the X-ray tube based
imaging experiment. The vials were sent to the AMNH
and three were exposed to X-rays. The X-ray 1 and 2

samples were irradiated for a duration (~42 min) need-
ed for a typical imaging experiment. The samples were
rotated during X-ray exposure to simulate a typical CT
acquisition. The X-ray source is a tungsten target and
the spectrum produced is a superposition of both tung-
sten characteristic X-ray peaks and bremsstrahlung
peaks. We also changed the experimental conditions to
study the effects of adding a Cu filter (X-ray 2) and
substantially increasing the exposure duration (X-ray
3) to the maximum typically used for an X-ray mi-
crotomography imaging scan (Table 1). The Cu filter
sits between the X-ray tube and the sample and reduces
sample exposure to the lower energy X-ray radiation.
One vial was not exposed and served as the experi-
mental control for the three irradiated samples.

Table 1. Experimental details of the X-ray irradiation of the
Murchison meteorite samples.

	Control	X-ray 1	X-ray 2	X-ray 3
Murchison mass (g)	0.5313	0.5048	0.5181	0.5152
X-ray tube potential (keV)	n/a	180	180	180
X-ray tube current (μ A)	n/a	120	120	120
Copper filter (0.3 mm)	n/a	no	yes	no
Exposure duration (min)	0	42.2	42.7	459
Total Dose (Gy)	0	~270	~10	~2950

Following the X-ray experiments at AMNH, the vi-
als were returned to GSFC and a portion of each sam-
ple (~250 mg) was flame sealed in a glass tube in 1 mL
Millipore ultrapure water and heated to 100°C for 24 h.
After hot-water extraction, half of the water extract was
desalted by cation exchange chromatography and the
NH₄OH eluate derivatized by *o*-phthalaldehyde/N-
acetyl-L-cysteine (OPA/NAC) and analyzed for amino
acids by ultrahigh performance liquid chromatography
with UV fluorescence detection and time of flight mass
spectrometry (LC-FD/ToF-MS) [4].

The other half of the water supernatant was acidi-
fied with 100 μ L 6M HCl, concentrated by drying under
vacuum and then analyzed by OPA/NAC derivatization
and LC-FD/ToF-MS. The amino acid and amine abun-
dances were determined by comparison of the UV fluo-
rescence and ToF-MS mass peak areas to the corre-
sponding areas of standards run under the same chro-
matographic conditions on the same day. The free ami-
no acid and amine concentrations in the extracts were
then determined from the average of three separate

measurements. The abundances and amino acid enantiomeric ratios of the irradiated meteorite extracts were compared to the non-irradiated control.

Results and Discussion:

Amino acid data. The abundances of D,L-aspartic and glutamic acids, D,L-serine, D,L-threonine, glycine, D,L-alanine, β -alanine, D,L- α -, D,L- β -, and γ -amino-*n*-butyric acid, α -aminoisobutyric acid, D,L-valine, D,L-isovaline, and ϵ -amino-*n*-caproic acid in the hot-water extracts were determined and the total amino acid abundances in the X-ray irradiated samples relative to the control are shown in Figure 1. We observed no change in the total amino acid concentrations (Fig. 1) or D/L ratios (Table 2) in the Murchison extracts after X-ray irradiation within analytical errors. These results are consistent with our previous study [3].

Table 2. Amino acid enantiomeric ratios (D/L) measured in the hot-water extracts of the control and X-ray exposed Murchison meteorite samples.

Amino Acid	Control (D/L)	X-ray 1 (D/L)	X-ray 2 (D/L)	X-ray 3 (D/L)
Asp	0.56 ± 0.15	0.56 ± 0.09	0.54 ± 0.11	0.60 ± 0.15
Glu	0.69 ± 0.17	0.69 ± 0.15	0.61 ± 0.10	0.75 ± 0.08
Ala	1.03 ± 0.11	1.02 ± 0.13	0.99 ± 0.06	1.07 ± 0.08
Iva	0.85 ± 0.06	0.86 ± 0.07	0.85 ± 0.05	0.93 ± 0.07

Amine data. The C1-C5 amine abundances of methylamine, ethylamine, propylamine, isopropylamine, isobutylamine, *sec*-butylamine, *tert*-pentylamine, *sec*-pentylamine, 3-aminopentane, 2-amino-3-methylbutane, 2-methylbutylamine, and isopentylamine in the hot-water extracts were determined and the total amine abundances in the X-ray irradiated samples relative to the control were determined (Fig. 1). Although there may be some evidence for amine decomposition in the X-ray 1 sample, the most surprising result is the two-fold increase in total amine abundances in the X-ray 2 and X-ray 3 samples relative to the control indicating significant amine (or amine precursor) production as a result of the X-ray irradiation. Since the amino acid and amine analyses were carried out on the same water extract, sample heterogeneity cannot explain the differences observed. In addition, there is no evidence of amino acid decomposition into amines during these irradiation experiments, therefore it is possible that the addition of the Cu filter and extended irradiation exposure time in the X-ray 2 and X-ray 3 experiments, respectively, contributed to an increase in degradation of the large insoluble macromolecular organic component (IOM) known to be present in Murchison [5]. Release of free amides in Murchison during irradiation that later formed amines by partial hydrolysis during hot

water extraction is also possible. Additional testing will be required to determine if the breakdown of IOM in Murchison is contributing to the production of amines or their precursors during X-ray irradiation exposure under these conditions.

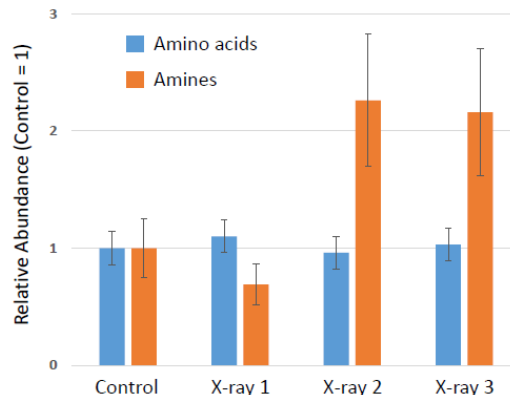


Fig. 1. Comparison of the relative abundances of free amino acids and amines in the hot-water extracts of powdered samples of the Murchison meteorite exposed to X-rays using the microfocus high resolution X-ray tube CT instrument at AMNH under different conditions compared to a control sample that was not irradiated. Instrument conditions for the samples are shown in Table 1.

Conclusions: We conclude that tube-based X-ray microtomography imaging tested under a variety of experimental conditions had no measurable effect on the amino acid content of the CM2 carbonaceous chondrite Murchison. However, a significant enhancement of the total amine abundance outside of experimental uncertainty was observed after X-ray irradiation exposure using a Cu filter (10 Gy dose), and for long exposure times without a Cu filter (2950 Gy), but not for short exposure without a filter (270 Gy). These data provide confidence in the use of μ CT and similar non-invasive methods for amino acid analyses of carbonaceous chondrites and returned asteroid samples from OSIRIS-REx and Hayabusa2. However, depending on the μ CT experimental conditions, significant changes to the amine content during irradiation are possible.

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